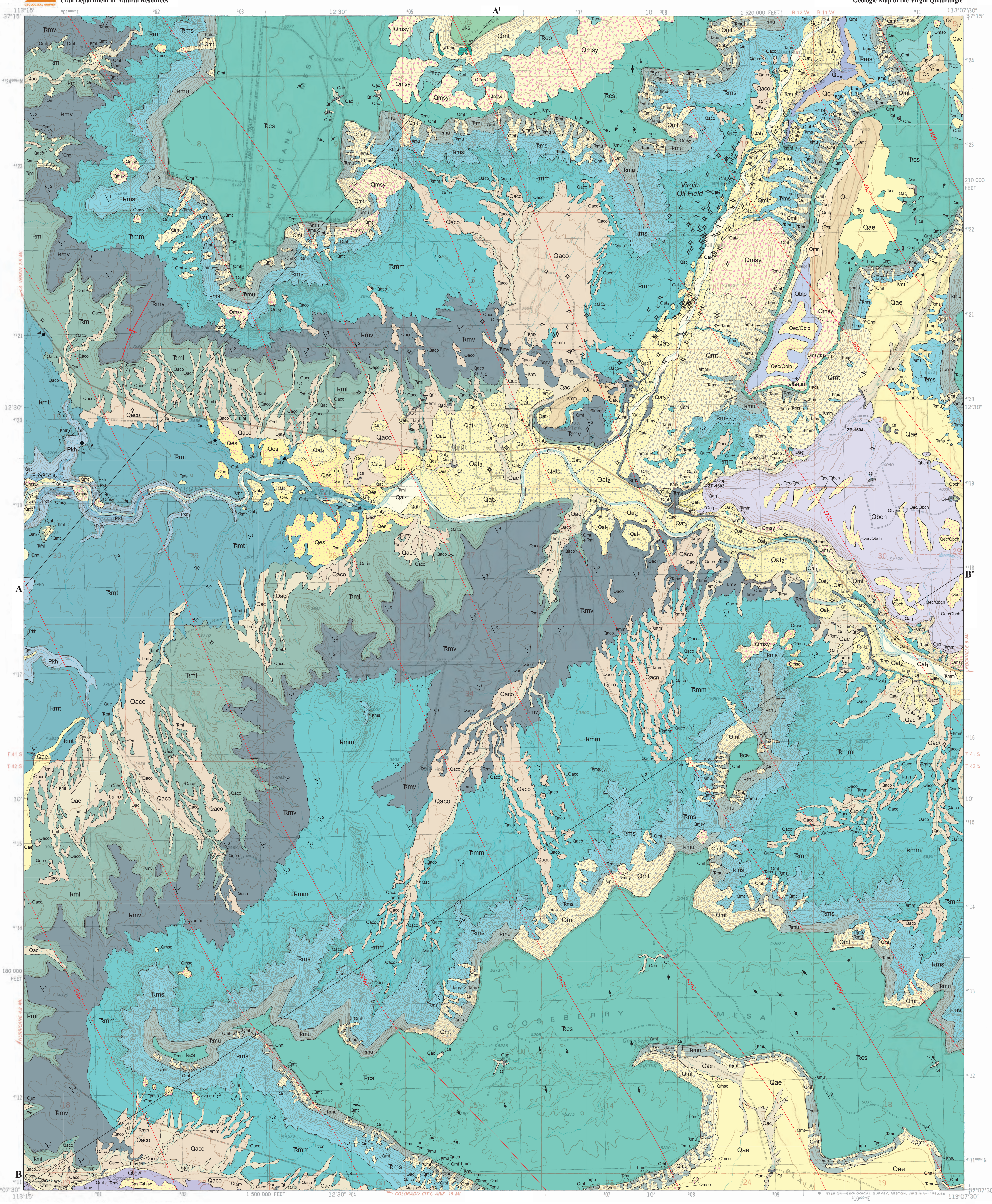
UTAH GEOLOGICAL SURVEY
a divison of
Utah Department of Natural Resources

Plate 1
Utah Geological Survey Map 231
Geologic Map of the Virgin Quadrangle



Base from U.S. Geological Survey,
Virgin 7.5' quadrangle, 1980

SCALE 1:24,000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

TOPOGRAPHIC CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
STRUCTURAL CONTOUR INTERVAL 100 FEET

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2008 MAGNETIC DECLINATION
AT CENTER OF SHEET

GEOLOGIC MAP OF THE VIRGIN QUADRANGLE, WASHINGTON COUNTY, UTAH

by
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2008

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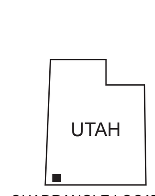
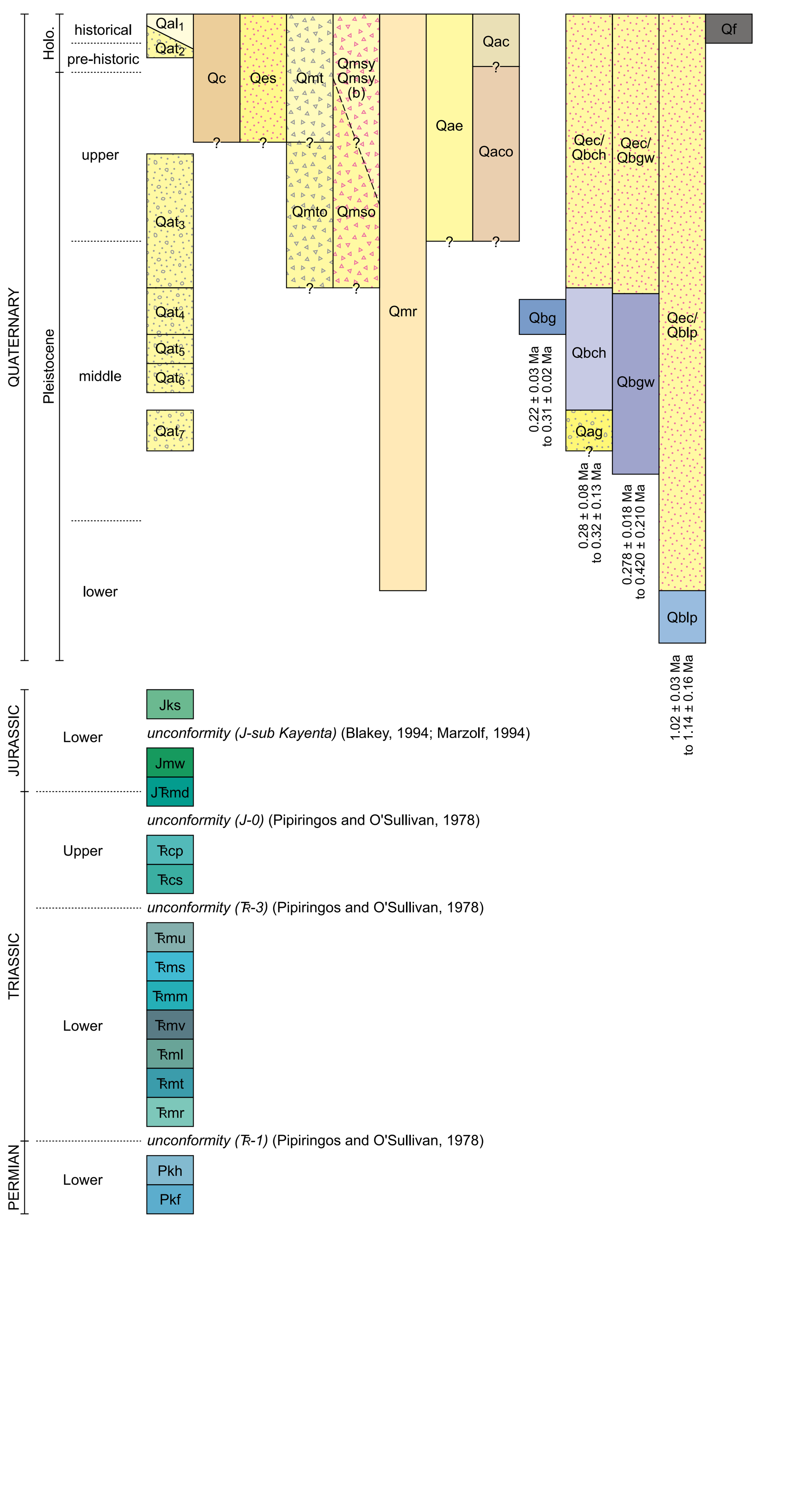


QUADRANGLE LOCATION

1	2	3	1. Pintura 2. Smith Mesa 3. The Guardian Angels
4		5	4. Hurricane 5. Springdale West
6	7	8	6. The Divide 7. Little Creek Mountain 8. Smithsonian Butte

ADJOINING 7.5' QUADRANGLE NAMES

CORRELATION OF GEOLOGIC UNITS



LITHOLOGIC COLUMN

ERA	SYSTEM	SERIES	FORMATION	MEMBER	SYMBOL	THICKNESS feet (meters)	LITHOLOGY
CENO.	QUAT.		surficial deposits		Q	0-50 (0-15)	
			basalt flows and associated deposits		Qb	0-400 (0-120)	
MESOZOIC	JURASSIC	Lower	Kayenta Fm	Springdale Ss. Mbr.	Jks	100+ (30+)	unconformity
			Moenave Formation	Whitmore Point Mbr.	Jmw	80 (24)	*Semionotus kanabensis*
				Dinosaur Canyon Member	JꞦmd	200 (60)	J-0 unconformity
	TRIASSIC	Upper	Chinle Formation	Petrified Forest Member	Ꞧcp	400 (120)	
				Shinarump Cgl. Mbr.	Ꞧcs	100-200 (30-60)	"picture stone" Ꞧ-3 unconformity
		Lower	Moenkopi Formation	upper red member	Ꞧmu	350-450 (105-135)	
				Shnabkaib Member	Ꞧms	400-500 (120-150)	gypsum "bacon striped"
				middle red member	Ꞧmm	400-450 (120-135)	
				Virgin Limestone Mbr.	Ꞧmv	100-130 (30-40)	
				lower red member	Ꞧml	250 (75)	
				Timpoweap Member	Ꞧmt	130 (40)	oil seeps
				Rock Canyon Cgl. Mbr.	Ꞧmr	0-7 (0-2)	Ꞧ-1 unconformity
PALEOZOIC	PERMIAN	Lower	Kaibab Formation	Harrisburg Member	Pkh	160 (50)	medial limestone brachiopods
				Fossil Mountain Member	Pkf	200+ (60+)	"black banded"

GEOLOGIC SYMBOLS

- Contact
- Axial trace of syncline; dashed where approximately located
- 4500 Structural contour drawn at base of Shinarump Conglomerate Member of the Chinle Formation (Ꞧcs); dashed where projected; contour interval 100 feet (30 m), datum is mean sea level
- Strike and dip of inclined bedding
- Approximate strike and dip of inclined bedding determined photogrammetrically
- Strike of near-vertical joint
- Pit (s = sand, g = gravel)
- Quarry (dimension stone)
- Oil seep
- Breccia pipe
- VR41-01 Sample location and number
- Spring
- Petroleum exploration drill hole, plugged and abandoned. Well location provided by Utah Department of Natural Resources, Division of Oil, Gas and Mining (OGM). It is unclear which wells produced over the 78-year history of the Virgin Oil Field. See Virgin Oil Field discussion at right for explanation. Current OGM records indicate 6 to 8 producers with all other wells having had shows of oil; however, it is likely that many of these were dry holes. Five records have been deleted from the map and some have been adjusted slightly to match the topographic base and field observations.

DESCRIPTION OF GEOLOGIC UNITS

QUATERNARY

Alluvial deposits

Qal1 **Alluvial-stream deposits** (Holocene) – Moderately to well-sorted clay to gravel deposits in large active drainages; includes terraces up to 10 feet (3 m) above modern channels; mapped along the Virgin River and North Creek; includes both the "active" channel and "modern" terrace levels of Hereford and others (1996) as mapped in the adjacent Springdale West quadrangle to the east by Willis and others (2002); Hereford and others (1996) determined that these sediments were deposited in the Virgin River channel in just the last few decades (since about A.D. 1940); these deposits were inundated during the major flood of January 2005; 0 to 30 feet (0-9 m) thick.

Qat2-7 **Alluvial-terrace deposits** (Holocene to middle Pleistocene) – Moderately to well-sorted sand, silt, and pebble to boulder gravel that forms level to gently sloping surfaces above modern drainages; subscript denotes height above active drainages; level 2 deposits include both "historic" and "settlement and late prehistoric" levels of Hereford and others (1996) as mapped in the adjacent Springdale West quadrangle to the east by Willis and others (2002) and are about 10 to 30 feet (3-9 m) above modern drainages; level 3 deposits are 30 to 90 feet (9-27 m), level 4 deposits are 90 to 140 feet (27-43 m), level 5 deposits are 140 to 190 feet (43-58 m), level 6 deposits are 190 to 270 feet (58-82 m), and level 7 deposits are in excess of 300 feet (90 m) above modern drainages; deposited primarily in stream-channel and flood-plain environments; degree of induration generally increases with height and thus with age of terraces from loose gravel of Qat2 to very well cemented gravel of Qat7 (Stage V calcic soil of Birkeland and others, 1991); 0 to 30 feet (0-9 m) thick.

Hereford and others (1996), working a few miles upstream, determined that terrace deposits less than about 30 feet (9 m) above the active river channel (mapped Qal1 and Qat2) are late Holocene in age (probably less than 1000 years old) and are related to short-term shifts (decades to a few hundred years) in the "modern" river (they showed that the river cycles through episodes of incision and backfilling of a few tens of feet with associated channel widening, meander shifts, and channel narrowing that are controlled primarily by short-term changes in climate and in the frequency, intensity, and duration of major storms). They did not recognize any middle or early Holocene river deposits; they estimated that the next older river deposits (here mapped as Qat3 and older deposits) are upper Pleistocene and older.

Though these older deposits have not been dated directly, their age can be estimated using calculated long-term incision rates determined from the relative height and age of basaltic lava that flowed into the ancestral channel of the Virgin River, combined with the amount of soil development and degree of lithification (Willis and Biek, 2001). The Crater Hill flow, which now sits on river gravel about 125 feet (40 m) above the modern river channel, is dated at about 300,000 years, suggesting a downcutting rate of 420 feet (130 m) per million years since emplacement; present height of remnants of the Lava Point basaltic lava flow that now cap the high point northeast of the town of Virgin indicates an additional 1175 feet (360 m) of incision in the 700,000 years prior for a downcutting rate of 1680 feet (510 m) per million years for that time period. Using these rates level 3 deposits are 70,000 to 215,000 years old; level 4 deposits, 215,000 to 310,000 years old; level 5 deposits, 310,000 to 340,000 years old; level 6 deposits, 340,000 to 385,000 years old and level 7 deposits are likely older than 405,000 years. However, these calculations do not take into account fluctuations in incision rates during this time (such as suggested by the Crater Hill flow), which could shift these age estimates significantly. In addition, short- and intermediate-term cyclicity in incision and backfilling of 50 feet (15 m) or more may skew ages of the lower-level deposits. Thus, age of Qat3 deposits, which would be affected most by this short-term cyclicity, may be significantly more or less than the calculated range.

Qag **Alluvial-gravel deposits** (middle Pleistocene) – Mappable in a few places beneath and extending out from under the Crater Hill lava flow; can be generally divided into two types: (1) mostly indurated, subrounded to well-rounded, boulder- to cobble-size, abundant sandstone and some limestone clasts and subangular to subrounded basalt clasts in a muddy to coarse sand matrix; clast supported; fining upward sequences repeat about every 6 feet (2 m); documents the location of the ancestral Virgin River bed; and (2) partially indurated, angular to subrounded, boulder- to cobble-size basalt clasts in a muddy to sandy matrix; matrix supported; clasts are randomly oriented and unsorted; probably deposited along the sloping edges of the ancestral Virgin River channel; older than Crater Hill flow (about 300,000 years old); 0 to 40 feet (0-12 m) thick.

Artificial deposits

Qf **Artificial fill deposits** (historical) – Artificial fill used to create small dams; consists of engineered fill and general borrow material; although only a few deposits have been mapped, fill should be anticipated in all areas with human impact, many of which are shown on the topographic base map; most deposits are less than 20 feet (6m) thick except for the diversion dam on the Virgin River, which is 110 feet (35 m) thick.

Colluvial deposits

Qc **Colluvial deposits** (Holocene to upper Pleistocene) – Poorly to moderately sorted, angular to subrounded, clay- to boulder-size, locally derived sediment deposited principally by slopewash and soil creep on moderate slopes; locally includes talus, alluvial, and eolian deposits; 0 to 30 feet (0-9 m) thick.

Eolian deposits

Qes **Eolian-sand deposits** (Holocene to upper Pleistocene) – Well- to very well sorted, very fine to medium-grained, well-rounded, mostly quartz sand; probably originates mostly from the weathering of Navajo and Kayenta Formations; mapped near the town of Virgin; locally mined for sand; deposited primarily on Timpoweap Member of Moenkopi Formation and alluvial-terrace deposits where the valley widens; 0 to 15 feet (0-4.5 m) thick.

Mass-movement deposits

Qmt, Qmto **Talus deposits** (Holocene to middle Pleistocene) – Very poorly sorted, angular boulders with minor fine-grained interstitial sediment; deposited mostly by rock fall on and at the base of steep slopes; form primarily from blocks that weather from the edges of lava flows, from the Shinarump Conglomerate Member of the Chinle Formation that caps both Hurricane and Gooseberry Mesas, and from the Springdale Sandstone Member of the Kayenta Formation that caps Smith Mesa within the quadrangle; locally contain small landslide and slump deposits; may include and are gradational with older, mixed alluvial-colluvial deposits farther downslope (Qaco); Qmt mantles steep slopes beneath cliffs and ledges, whereas Qmto mantles and armors a hillside along North Creek now separated from the main slope due to retreat of the cliff; 0 to 20 feet (0-6 m) thick.

Qmsy, Qmsy(b), Qmso **Landslide deposits** (Holocene to middle Pleistocene) – Very poorly sorted, clay- to boulder-size, locally derived debris in chaotic, hummocky mounds; form on steep slopes beneath lava flows, Springdale Sandstone Member of the Kayenta Formation, and Shinarump Conglomerate Member of the Chinle Formation; basal slip surfaces develop mostly in Petrified Forest Member of the Chinle Formation and Shnabkaib and middle red members of the Moenkopi Formation; younger deposits (Qmsy) rest on modern hillsides whereas older deposits (Qmso) are chaotic bedrock debris armored by regolith and isolated from adjacent slopes due to slope retreat; however, research shows that landslides with subdued morphology are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003); Qmsy(b) consists of large blocks of Lava Point basaltic lava flow that collapsed and slid as softer underlying Petrified Forest Member of the Chinle Formation eroded (because of the gentle east dip of the underlying sedimentary rocks, the flow is in contact with the resistant Shinarump Conglomerate Member along its western margin, creating a straight cliff, but overlies the Petrified Forest Member along its eastern margin, resulting in large slide blocks); 0 to 100 feet (0-30 m) thick.

Qmr **Residual deposits of Lava Point flow** (Holocene to lower Pleistocene) – Residual lag of angular to subangular basalt blocks derived from the Lava Point flow; includes very rare blocks of sandstone, particularly in the northern and eastern part of these deposits, possibly derived from the Kayenta Formation – currently, sandstone cliffs of these rocks are about one mile (1.6 km) or more east of the residual lag deposits, indicating significant slope retreat in the past one million years since the lava flowed; also includes one small area just north of Lava Point flow outcrop of subrounded to rounded pebbles and cobbles of sandstone, limestone, and quartz monzonite porphyry (presumably from the Pine Valley Mountain intrusion to the northwest), which may represent ancestral North Creek stream gravels; although Lava Point basalt is virtually the only rock type seen in these deposits, nowhere is it clearly in place, suggesting that it represents a lag of basalt let down by erosion of underlying Petrified Forest Member of the Chinle Formation; thickness uncertain, but probably up to several tens of feet thick.

Mixed-environment deposits

Qae **Mixed alluvial and eolian deposits** (Holocene to upper Pleistocene) – Moderately to well-sorted, clay- to sand-sized alluvial sediment that locally includes abundant eolian sand and minor gravel; exhibits stage II calcic soil development (Birkeland and others, 1991); mapped in Little Plain and Dalton Wash valleys in the southeast and northeast corners of the quadrangle; 0 to 50 feet (0-15 m) thick.

Qac, Qaco **Mixed alluvial and colluvial deposits** (Holocene to upper Pleistocene) – Poorly to moderately sorted, clay- to boulder-sized, locally derived sediment; gradational with alluvial, colluvial, and mixed alluvial and eolian deposits; younger material (Qac) is deposited in swales and minor drainages whereas older deposits (Qaco) form incised, inactive, gently sloping surfaces gradational with and downslope from colluvial and talus deposits; include terrace deposits too small to map separately; 0 to 20 feet (0-6 m) thick.

Basaltic lava flows and related deposits – Major and trace-element geochemistry and $^{40}Ar/^{39}Ar$ raw data are available on the Utah Geological Survey Web site (geology.utah.gov/online/analytical_data.htm); rock names are derived from the TAS diagram of LeBas and others (1986).

Qbg **Grapevine Wash lava flow** (middle Pleistocene) – Medium-gray, weathering dark-brownish-gray to dark-brownish-black, fine-grained olivine basalt to basaltic trachyandesite lava flow; vesicular to dense; locally jointed; flow textures locally evident on upper surfaces; rubbly base where exposed; erupted from several vents on the Lower Kolob Plateau, including Firepit Knoll and Spendlove Knoll cinder cones, about 6 miles (10 km) northeast of the quadrangle; five $^{40}Ar/^{39}Ar$ plateau ages range from 0.22 ± 0.03 Ma to 0.31 ± 0.02 Ma (Willis and Hylland, 2002); mapped along North Creek in the northeast corner of the quadrangle; 10 to 20 feet (3-6 m) thick.

Qec/Qbch, Qbch **Crater Hill lava flow** (middle Pleistocene) **and associated eolian deposits** (Holocene to middle Pleistocene) – Medium-gray, weathering dark-brownish-gray to dark-brownish-black, olivine basalt lava flow (Qbch); vesicular to dense; locally jointed; upper surface has large arcuate pressure ridges; rubbly base where exposed; erupted from vent at Crater Hill cinder cone just east of quadrangle (Willis and others, 2002); flowed into, and overflowed, ancestral Scoggins and Coalpits Washes, then flowed southward into the ancestral Virgin River, ponded, then continued westward about 5 miles (8 km) into the Virgin quadrangle; lava dam created Lake Grafton in the Virgin River drainage and Coalpits Lake in Coalpits Wash (Hamilton, 1979; Hamilton, undated; Willis and others, 2002); Qec/Qbch denotes partial cover of eolian sand and calcic soil up to several feet thick; flow is typically 3 to 80 feet (1-24 m) thick, but locally up to 400 feet (120 m) thick where it ponded in ancestral Virgin River channel (Willis and others, 2002); base is about 125 feet (38 m) above modern Virgin River channel, but appears higher along State Highway 9 because the cliff face exposes a higher level of the dish-shaped flow; re-interpreted by Willis and others (2002) to represent a single eruptive episode rather than the multi-eruptive history proposed by Nielson (1977) and Downing (2000); three samples from the Springdale West quadrangle yielded $^{40}Ar/^{39}Ar$ plateau ages that range from 0.28 ± 0.08 Ma to 0.32 ± 0.13 Ma (UGS unpublished data).

Qec/Qbgw, Qbgw **Gould Wash lava flow** (middle Pleistocene) **and associated eolian deposits** (Holocene to middle Pleistocene) – Dark-gray, very fine grained olivine basalt lava flow (Qbgw) with abundant olivine phenocrysts; yielded an $^{40}Ar/^{39}Ar$ isochron age of 0.278± 0.018 Ma (Downing, 2000), however, sample VR41-08, just off the quadrangle boundary yielded an $^{40}Ar/^{39}Ar$ isochron age of 0.420 ± 0.005 and a plateau age of 0.420 ± 0.210 (UGS unpublished data); the flow exhibits a level of incision comparable to the adjacent 400,000-year-old Divide lava flow, and so is likely about 400,000 years old; however, note that Downing's age is within the margin of error of the more recent date; erupted from two cinder cones just off the south edge of the quadrangle (Hayden, 2004); Qec/Qbgw denotes partial cover of eolian sand and calcic soil up to several feet thick; mapped south of State Highway 59 in the southwest corner of the quadrangle; generally 20 to 30 feet (6-9 m) thick.

Qec/Qblp, Qblp **Lava Point lava flow** (lower Pleistocene) **and associated eolian deposits** (Holocene to lower Pleistocene) – Medium-gray, weathering to dark-brownish-gray to dark-brownish-black, phenocryst-poor, olivine basaltic trachyandesite to basaltic andesite lava flow (Qlbp); vesicular to dense; locally jointed; upper surface of flow generally strongly weathered; rubbly base where exposed; flowed down ancestral North Creek and now forms inverted valley that lies about 1300 feet (400 m) above North Creek and the Virgin River; $^{40}Ar/^{39}Ar$ plateau ages range from 1.02 ± 0.03 to 1.14 ± 0.16 Ma with sample VR41-01 yielding an age of 1.06 ± 0.01 Ma (Biek, 2007; Willis and Hylland, 2002); Qec/Qblp denotes partial cover of eolian sand and calcic soil up to several feet thick; typically 20 to 40 feet (6-12 m) thick.

unconformity

JURASSIC

Kayenta Formation

Blakey (1994) and Marzolf (1994) proposed a major regional unconformity at the base of the Springdale Sandstone Member of the Moenave Formation that would restrict that formation to the Dinosaur Canyon and Whitmore Point Members. Subsequent work by Lucas and Heckert (2001), Molina-Garza and others (2003), and Lucas and Tanner (2007a) also suggested that the Springdale Sandstone is more closely related to, and should be made the basal member of, the Kayenta Formation.

Jks **Springdale Sandstone Member** (Lower Jurassic) – Mostly pale-reddish-purple to pale-reddish-brown, moderately sorted, fine- to medium-grained, medium- to very thick bedded sandstone, and minor, thin, discontinuous lenses of intraformational conglomerate and thin interbeds of moderate-reddish-brown or greenish-gray mudstone and siltstone; has large lenticular and wedge-shaped, low-angle, medium-to large-scale cross-bedding; secondary color bands that vary from concordant to discordant to cross-beds are common in the sandstone; weathers to rounded cliffs and ledges that cap Smith Mesa within the quadrangle; contains locally abundant petrified and carbonized fossil plant remains; deposited in braided-stream and minor flood-plain environments (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; and DeCourten, 1998); incomplete thickness of about 100 feet (30 m); Willis and others (2002) reported a total thickness of 90 to 150 feet (27-46 m) in the Springdale West quadrangle to the east.

unconformity (J-sub Kayenta) (Blakey, 1994; Marzolf, 1994)

JURASSIC/TRIASSIC

Moenave Formation

Jmw **Whitmore Point Member** (Lower Jurassic) – Interbedded, pale-reddish-brown, greenish-gray, and grayish-red mudstone and claystone, with thin-bedded, moderate-reddish-brown, very fine to fine-grained sandstone and siltstone; siltstone is commonly thin bedded to laminated in lenticular or wedge-shaped beds; claystone is generally flat bedded; contains several 3- to 18-inch-thick (7-48 cm), bioturbated, cherty, very light gray to yellowish-gray dolomitic limestone beds with algal structures, some altered to jasper, and fossil fish scales of *Semionotus kanabensis*; forms poorly exposed ledgy slope; upper, unconformable contact is placed at the base of the thick- to very thick bedded sandstone ledge of the Springdale Sandstone, which creates a pronounced break in slope; deposited in low-energy lacustrine and fluvial environments (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; and DeCourten, 1998); 81 feet (24 m) thick at the south end of Smith Mesa.

JꞦmd **Dinosaur Canyon Member** (Lower Jurassic to Upper Triassic) – Uniformly colored, interbedded, generally thin-bedded, moderate-reddish-brown to moderate-reddish-orange, very fine to fine-grained sandstone, very fine grained silty sandstone, and lesser siltstone and mudstone; ripple marks and mud cracks common; forms ledgy slope; conformable and gradational upper contact placed at the base of the lowest light-gray, thin-bedded, dolomitic limestone; deposited on broad, low flood plain that was locally shallowly flooded (fluvial mud flat) (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; and DeCourten, 1998); 236 feet (72 m) thick at the south end of Smith Mesa.

unconformity (J-0) of Pipiringos and O'Sullivan (1978), who thought it was at the Jurassic-Triassic boundary; however, the Jurassic-Triassic boundary is now considered to be within the Dinosaur Canyon Member of the Moenave Formation (Molina-Garza and others, 2003; Lucas and Tanner, 2007b).

TRIASSIC

Chinle Formation

Ꞧcp **Petrified Forest Member** (Upper Triassic) – Highly variegated, light-brownish-gray, pale-greenish-gray, to grayish-purple smectitic shale, mudstone, siltstone, and claystone, with lesser thick-bedded, resistant sandstone and pebble to small cobble conglomerate near base that is up to 30 feet (9 m) thick; clasts are primarily chert and quartzite; contains minor chert, nodular limestone, and very thin coal lenses up to 0.5 inch (1 cm) thick; mudstone weathers to a "popcorn" surface due to expansive clays and causes road and building foundation problems; contains locally abundant, brightly colored fossilized wood including highly fractured logs up to 10 feet (3 m) long with a diameter of 1.5 feet (0.5 m); weathers to badland topography; prone to landsliding, especially along steep hillsides; mostly slope forming; upper contact is not exposed, but regionally corresponds to a color change between the purplish mudstone below and the moderate-reddish-brown, fine-grained sandstone above; a thin chert-pebble conglomerate typically marks this contact throughout Washington County (James I. Kirkland, Utah Geological Survey, verbal communication, November 19, 2004); small chert pebbles locally litter the slope near the contact; deposited in lacustrine, flood-plain, and braided-stream environments (Dubiel, 1994); 406 feet (124 m) thick at Smith Mesa.

Ꞧcs **Shinarump Conglomerate Member** (Upper Triassic) – Varies from grayish-orange to moderate-yellowish-brown, medium- to coarse-grained sandstone with locally well-developed limonite bands ("picture stone" or "landscape rock") to moderate-brown pebble conglomerate with subrounded clasts of quartz, quartzite, and chert; mostly thick- to very thick bedded with both planar and low-angle cross-stratification; contains locally abundant, poorly preserved petrified wood fragments and common, highly fractured petrified logs several feet in length; forms the dark-brown to moderate-yellowish-brown cap rock of Gooseberry and Hurricane Mesas; upper contact is placed between the yellowish-brown sandstone and pebbly sandstone of the Shinarump Conglomerate below and the base of the varicolored smectitic mudstone beds of the Petrified Forest Member above; variable in composition and thickness because it represents stream-channel deposition over Late Triassic paleotopography (Dubiel, 1994); 124 feet (38 m) thick along Hurricane Mesa road; generally ranges from 100 to 200 feet (30-60 m) thick.

unconformity (Ꞧ-3) (Pipiringos and O'Sullivan, 1978)

Moenkopi Formation

Ꞧmu **Upper red member** (Lower Triassic) – Moderate-reddish-brown, thin-bedded siltstone and very fine grained sandstone with some thin gypsum beds and abundant discordant gypsum stringers; ripple marks common in the siltstone; forms a steep slope with a few sandstone ledges; locally includes 20-foot-thick (6 m), fine-grained, resistant sandstone near base; upper contact is based on lithologic change between the ledges of moderate-reddish-brown siltstone and sandstone of the upper red member below to the cliff of moderate-yellowish-brown sandstone of the Shinarump Conglomerate Member above; deposited in coastal-plain and tidal-flat environments (Dubiel, 1994); 443 feet (135 m) thick at Hurricane Mesa; ranges 350 to 450 feet (105-135 m) thick.

Ꞧms **Shnabkaib Member** (Lower Triassic) – Light-gray to pale-red, gypsiferous siltstone with bedded gypsum and several thin interbeds of dolomitic, unfossiliferous limestone near the base; upper part is very gypsiferous and weathers to a powdery soil commonly covered by microbiotic crust; forms ledge-slope "bacon-striped" topography; prone to landsliding; upper gradational contact, marked by a prominent color change and lesser slope change, is placed at the top of the highest light-colored, thick gypsum bed, above which are steeper slopes of laminated to thin-bedded, moderate-reddish-brown siltstone and sandstone beds of the upper red member; deposited on broad coastal shelf of very low relief where minor fluctuations in sea level produced interbedding of evaporites and red beds (Dubiel, 1994); 510 feet (155 m) thick at Hurricane Mesa; generally 400 to 500 feet (120-150 m) thick.

Ꞧmm **Middle red member** (Lower Triassic) – Interbedded moderate-red to moderate-reddish-brown siltstone, mudstone, and thin-bedded, very fine grained sandstone with thin interbeds and veinlets of greenish-gray to white gypsum; forms slope with several ledge-forming gypsum beds near base; upper contact is placed at the base of the first thick gypsum bed where the moderate-reddish-brown siltstone below gives way to banded, greenish-gray gypsum and pale-red siltstone above; deposited in tidal-flat environment (Dubiel, 1994); 400 to 450 feet (120-135 m) thick.

Ꞧmv **Virgin Limestone Member** (Lower Triassic) – Three distinct medium-gray to yellowish-brown limestone ledges interbedded with nonresistant, moderate-yellowish-brown, muddy siltstone, pale-reddish-brown sandstone, and light-gray to grayish-orange-pink gypsum; limestone beds are typically 5 to 10 feet (1.5-3 m) thick and contain five-sided crinoid columnals and *Composita* brachiopods; upper contact is drawn at the top of the highest limestone bed; deposited in shallow-marine environment (Dubiel,1994); 145 feet (44 m) thick south of Hurricane Mesa; generally 100 to 130 feet (30-40 m) thick.

Ꞧml **Lower red member** (Lower Triassic) – Moderate-reddish-brown siltstone, mudstone, and fine-grained, slope-forming sandstone; locally, the color of the lower part is irregularly altered to yellowish-orange probably due to hydrocarbon migration; generally calcareous and has interbeds and stringers of gypsum; ripple marks and small-scale cross-beds are common in the siltstone; upper contact drawn at the color change from moderate-reddish-brown siltstone of the lower red member to moderate-yellowish-brown, muddy siltstone, typically about 3 feet (1 m) thick, which underlies the base of the first limestone ledge of the Virgin Limestone Member; deposited in tidal-flat environment (Dubiel, 1994); about 250 feet (75 m) thick.

Ꞧmt **Timpoweap Member** (Lower Triassic) – Upper part is grayish-orange, thin- to thick-bedded, slightly calcareous, very fine grained sandstone with thin-bedded siltstone and mudstone; lower part is light-gray to grayish-orange, thin- to thick-bedded limestone and cherty limestone that weathers light-brown with a rough, "meringue-like" surface due to blebs of chert; contains gastropods, brachiopods, and rare ammonites; some beds include euhedral pyrite crystals up to 1/4 inch (1 cm); member overall weathers yellowish-brown and forms ledges or low cliff; contains petroliferous outcrops and oil seeps in Timpoweap Canyon of the Virgin River and its tributaries to the north where the upper Timpoweap is exposed (Blakey, 1979); main producing interval of Virgin oil field; upper contact placed at the color change from grayish-orange sandstone of the Timpoweap Member below to the moderate-reddish-brown siltstone of the lower red member above; locally quarried for dimension stone; deposited in shallow, north-trending marine trough, filling paleotopography on top of the Kaibab Formation (Nielson, 1981); thickness approximately 130 feet (40 m).

Ꞧmr **Rock Canyon Conglomerate Member** (Lower Triassic) – Regionally consists of two main rock types: (1) pebble to cobble, clast-supported conglomerate with subrounded to rounded chert and minor limestone clasts derived from Harrisburg strata, which was deposited as channel fill in paleovalleys (Nielson, 1991) and as a thinner and sandier breccia-to-conglomerate fill above a breccia pipe collapse feature in Harrisburg strata, and (2) thin breccia or regolith deposit (Nielson, 1991) on underlying Harrisburg Member strata; in this quadrangle, only the thin breccia of type (2) is present in a few places along the Virgin River in the west half of the quadrangle; upper gradational contact is placed at the base of the first laterally extensive yellowish-brown limestone of the Timpoweap Member; 0 to 7 feet (0-2 m) thick.

unconformity (Ꞧ-1) (Pipiringos and O'Sullivan, 1978)

PERMIAN

Kaibab Formation

Pkh **Harrisburg Member** (Lower Permian) – Interbedded thin- to very thick bedded gypsum, gypsiferous mudstone, and limestone, some of which contains chert; laterally variable; mostly slope-forming, but includes a medial, resistant, cliff- and ledge-forming, white chert and limestone interval; gypsum dissolution causes separation of limestone blocks along joints creating an area locally called "the cracks" along the Virgin River canyon in SE1/4SE1/4 section 19 and NE1/4NE1/4 section 30, T. 41 S., R. 12 W.; one breccia pipe collapse feature is mapped in NW1/4SE1/4 section 19, T. 41 S., R. 12 W. (Wenrich and Huntoon, 1989); upper unconformable contact with the Rock Canyon Conglomerate Member, or, where not present, the Timpoweap Member of the Moenkopi Formation, is typically within a ledge- or cliff-forming interval and is difficult to pick out; however, generally, irregularly bedded Harrisburg Member below weathers grayer and more blocky than thin, gently undulating Timpoweap Member above that weathers more brown and platy; Rock Canyon Conglomerate, if present, is the thin interval of conglomerate and/or breccia tucked between these two similar lithologies; deposited in a complex succession of sabkha and shallow-marine environments (Nielson, 1981); 160 feet (50 m) thick.

Pkf **Fossil Mountain Member** (Lower Permian) – Light-gray, thick- to very thick bedded, planar-bedded, laterally consistent, cherty limestone and fossiliferous limestone; whole silicified brachiopods abundant near top; "black-banded" due to abundant reddish-brown, brown, and black chert; forms prominent cliff; upper conformable contact drawn at the break in slope between the limestone cliff of the Fossil Mountain Member and the gypsiferous mudstone and gypsum slope of the Harrisburg Member; deposited in shallow-marine environment (Nielson, 1986); 208 to 286 feet (63-87 m) thick in the Hurricane quadrangle to the west (Nielson,1981; Biek, 2003), but only about 200 feet (60 m) is exposed within the quadrangle.

Subsurface unit

Pzu **Paleozoic, undivided** – Shown on cross section only.

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VIRGIN OIL FIELD

With the drilling of the first well in 1907, the Virgin oil field has the distinction of being the oldest oil field in Utah (Heylmun, 1993). The discovery well was drilled in an attempt to locate the down-dip source of the oil seeps observed in Timpoweap Canyon and its tributaries, about 3 miles (6 km) southwest of the field (Richardson, 1908). The trapping mechanism is generally believed to be stratigraphic due to the lack of significant structural closure, the depressured nature of the field at discovery, interpretations of the depositional environment, the variability of porosity and permeability over relatively short distances, and the differences in pay thickness, which varied from 1 to 12 feet (0.3-3 m) but averaged only 4 feet (1.2 m) thick (Blakey, 1979). Production was primarily from the Timpoweap Member of the Moenkopi Formation (Gregory, 1950) with a possible contribution from the subjacent Kaibab Formation (Brandt, 1989). Productive depths ranged from 475 to 800 feet (145-244 m) with an average of 550 feet (168 m) (Bahr, 1963). The brown to black oil ranged from 22° API sour crude at the shallow south end of the field, to 32° API sweet crude at the deeper north end and had a mixed paraffin-asphalt base (Heylmun, 1993). Field development and production occurred intermittently with the last production report dated April 1985 (Christopher J. Kierst, Division of Oil, Gas and Mining, verbal communication, October 29, 2004). Cummulative production of over 206,000 barrels of oil is estimated since production records were not preserved prior to 1927. The productive area included about 200 acres (0.8 km^2) (Heylmun, 1993). It is unclear how many wells produced over the 78-year history of the field. Current OGM records indicate 6 to 8 producers; however, Gregory (1950) reported that by 1939 there were 113 wells of which 12 were producers, 21 had a show of oil, 66 were dry and 14 were plugged and abandoned. Hauptman (1952) reported 136 wells drilled with 53 producers at that time. Subsequently, Heylmun (1961) reported 140 wells with 30 of them producing. A field study by OGM in 1992 located 141 wells. All known wells are plugged and abandoned (Christopher J. Kierst, verbal communication, October 29, 2004).